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13. ABSTRACT (Maximum 200 words)

The main focus of research under AFOSR Grant F49620-92-J-0092 is to investigate the global and local transport of metallic ions in the upper atmosphere, in particular the layering of ionization, through use of comprehensive numerical models which account for realistic meteoric sources, chemical conversions and sinks, and transport by molecular and eddy diffusion, winds, and electric fields. The ultimate goal is to better understand the mechanisms producing ionization layers, and ultimately the seasonal, latitudinal, local time, and temporal variations in the occurrences of ionization layers. Plasma layering can affect HF communications by introducing new reflection paths thus complicating the propagating modes, and presumably in extreme cases producing blanketing effects. In addition, plasma irregularities may also accompany the sharp gradients characterizing the plasma layers.

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ANNUAL TECHNICAL REPORT

AFOSR Grant F49620-92-J-0092

entitled

METALLIC IONS AND ATOMS IN THE UPPER ATMOSPHERE

15 October 1992
Prof. Jeffrey M. Forbes, Principal Investigator
Center for Space Physics and
Department of Aerospace and Mechanical Engineering
Boston University, Boston, MA 02215

1. OVERVIEW

The main focus of research under AFOSR Grant F49620-92-J-0092 is to investigate the global and local transport of metallic ions in the upper atmosphere, in particular the layering of ionization, through use of comprehensive numerical models which account for realistic meteoric sources, chemical conversions and sinks, and transport by molecular and eddy diffusion, winds, and electric fields. The ultimate goal is to better understand the mechanisms producing ionization layers, and ultimately the seasonal, latitudinal, local time, and temporal variations in the occurrences of ionization layers. Plasma layering can affect HF communications by introducing new reflection paths thus complicating the propagating modes, and presumably in extreme cases by producing blanketing effects. In addition, plasma irregularities may also accompany the sharp gradients characterizing the plasma layers.

There are four separate lines of investigation actively being pursued under this grant:

(1) Local Na/Na^+ Chemistry and Transport Simulation. This is a high resolution two-dimensional model in the height/latitude frame for daytime conditions only, extending from 60 to 300 km. This model includes the complete photochemistry and vertical transport of all important oxygen/hydrogen/nitrogen neutral and ionized compounds, consistently coupled to to the Na and Na^+ chemistries. Our purposes are twofold: (a) to understand the conditions necessary for the formation of Na^+ layers; and (b) to understand the coupling between the Na and Na^+ chemistries, and the formation of neutral Na layers that are observed to correlate with "sporadic" ionization layers.

(2) Global Fe^+ Transport Simulation. This model is intended to prescribe the global distributions of meteoric sources and effective chemical sinks of Fe^+, and knowing the global distributions of winds and electric fields, for instance from the NCAR TIEGCM, to simulate the distribution of Fe^+ around the globe. We intend to explain the observed E and F-region densities of Fe^+ using this model, and to make predictions regarding the response and recovery of global Fe^+ distributions in conjunction with meteor showers and geomagnetic storms.

(3) Local Ion Layer Simulation. This model is two dimensional in the height/local time frame, and will be used to understand the conditions necessary for the creation of ionization layers at all local times, but particularly at night. This is a high resolution model with primary emphasis on Fe^+. A simple chemistry is used near the bottom boundary of the model (100 km) to remove Fe^+. We intend to examine the role of NO^+ in forming layers at night, particularly those referred to as "intermediate layers", which are observed

to descend downward from below the F-region peak.

(4) Observational Study of Plasma Structure over Millstone Hill During a May 28, 1992, experiment over Millstone Hill, a set of high resolution plasma density data was obtained using new modes or radar operation and software analysis. The experiment was set up as part of a Mitre Corporation sponsored initiative to look at the effects of mid-latitude ionospheric structure on HF communications and surveillance systems. These data are being examined to characterize the plasma structures in general, and also to look for the possible presence of plasma layers that might be connected with the modeling activities above.

Initiative (1) is being undertaken as a collaborative study between the P.I., and Co-Investigator R.G. Roble at NCAR. The model resides at NCAR and is an extension of a previous model developed by R. Roble. (2) is being undertaken as the Ph.D. Dissertation work of Mr. Leonard Carter, under the direction of the P.I. Studies (4) and (5) are being pursued by Mr. Randy Godwin as part of his Ph.D. Dissertation work, under the direction of the P.I. He is supported by the MITRE Corporation for his involvement in this work.

Below, the current status of work for each of these initiatives is outlined, along with some outlook for future direction of the work.

2. CURRENT STATUS and FUTURE DIRECTION

Local Na/Na^+ Chemistry and Transport Simulation. The full sodium chemistry as recommended by Plane (Int. Rev. Phys. Chem, 10, 1991, 55-106) have been incorporated into the model, along with the hydrated ion chemistry scheme of Richter and Sechrist (Geophys. Res. Lett., 6, 183-186, 1979). In addition, a wind and electric field distribution geared to 18° latitude have been incorporated into the model. One of our initial goals will be to investigate the conditions necessary to produce the descending daytime layers observed over Townesville, Australia (Wilkinson et. al., Geophys. Res. Lett., 19, 95-98, 1992). Only recently have we overcome some initial computational problems, and been able to produce our first baseline computation of Na and Na^+ densities. These preliminary results are depicted in Figures 1 and 2. Our intention is to further experiment with various wind fields and Na/Na^+ source distributions so that we can better understand the important controlling parameters in the problem. We will then attempt to simulate the daytime descending layers observed over Townesville, and to examine the corresponding Na densities to understand their behavior. This study will then be reported on in the literature. In future studies we intend to examine

other metallic species (Fe^+, Mg^+, etc.) and to examine the breakup of a descending layer to the interference between a gravity wave and the background tidal motions responsible for the layer descent. Such breakup events have been observed by the EISCAT radar.

Global Fe^+ Transport Simulation. As a precursor to a full three-dimensional simulation with TIEGCM plasma drifts due to winds and electric fields as input (our final goal in this model development), we have developed first a time-dependent one-dimensional model of Fe^+ wherein the input neutral and ion densities, winds, and electric fields are based on simple specifications and/or convenient empirical models. The Finite Element Simulation (FES) Code developed under a previous AFOSR grant to Boston University has been modified for this purpose. We are presently in the process of experimenting with various wind and electric field specifications to verify that the code is working properly, and to understand their role in redistributing Fe^+. A typical set of [Fe^+] contours corresponding to a southward wind of 50 m/sec and zero electric field is given in Figure 3. The next computational step will be to expand the domain to two and three dimensions, and to examine the full global transport effects. This partiuclar model will not be run at very high resolution to simulate layering of Fe^+, and will not include the complex chemistry below 100 km. Instead, an effective loss (downward flux) will be imposed at the lower boundary based on our high-resolution studies described in (1) and (3).

Local Ion Layer Simulation. This work has not yet been initiated. It will essentially consist of developing a high-resolution version of the one-dimensional model described above, with somewhat more complex chemistry above 100 km, to concentrate on the layering process, particularly at night. We will examine the role of NO^+ in the layer process. At this point it is an open question as to whether the so-called "intermediate layers" descending downward from the lower F-region are metallic, or consist primarily of ambient molecular ions (whose chemical lifetimes are much longer at night due to the lower ionization densities).

Observational Study of Plasma Structure over Millstone Hill During the 24-hour period of the Millstone Hill experiment, considerable plasma structure was observed. Figure 4 illustrates some preliminary electron density profiles for select times during the experiment. (These data are "preliminary" since they are as yet uncalibrated and corrected; however the relative variations are expected to remain in tact). Note the significant structure, and in some cases, layering of the plasma (i.e., large spikes). When these data are plotted vs. time, similar structure is observed with rspect to time. We believe that much of this structure is due to gravity waves. Correspondingly, we have begun to examine vertical and temporal spectra of the data, as illustrated in Figure 5. At this point our work is exploratory. We have

begun, for instance, to apply band-pass filters and to perform inverse FFT's to obtain time filtered plots as in Figure 6, as well as time-filtered and space-time-filtered depictions of these data. Our goal in this initial work will be to quantitatively describe, for the first time, the characteristics of plasma structure for the mid-latitude ionosphere. We hope to accompany this by a theoretical interpretation in terms of gravity waves, either as perturbers of the ion densities through chemical effects or through wind-shear layering effects. One question that must be addressed, for instance, is how such small-scale structures can be maintained in the topside F-region in the presence of rapid diffusion.

3. PERSONNEL

Personnel supported under this grant include:

[1.] Prof. Jeffrey M. Forbes, Principal Investigator

[2.] Mr. Leonard Carter, candidate for the Ph.D. in Applied Physics

Other personnel contributing to the research under this grant, but not supported by salary:

[1.] Dr. Raymond G. Roble, Co-Investigator, NCAR/HAO

[2.] Mr. Randy Godwin (MITRE Corp.), candidate for the Ph.D. in Electrical Engineering.

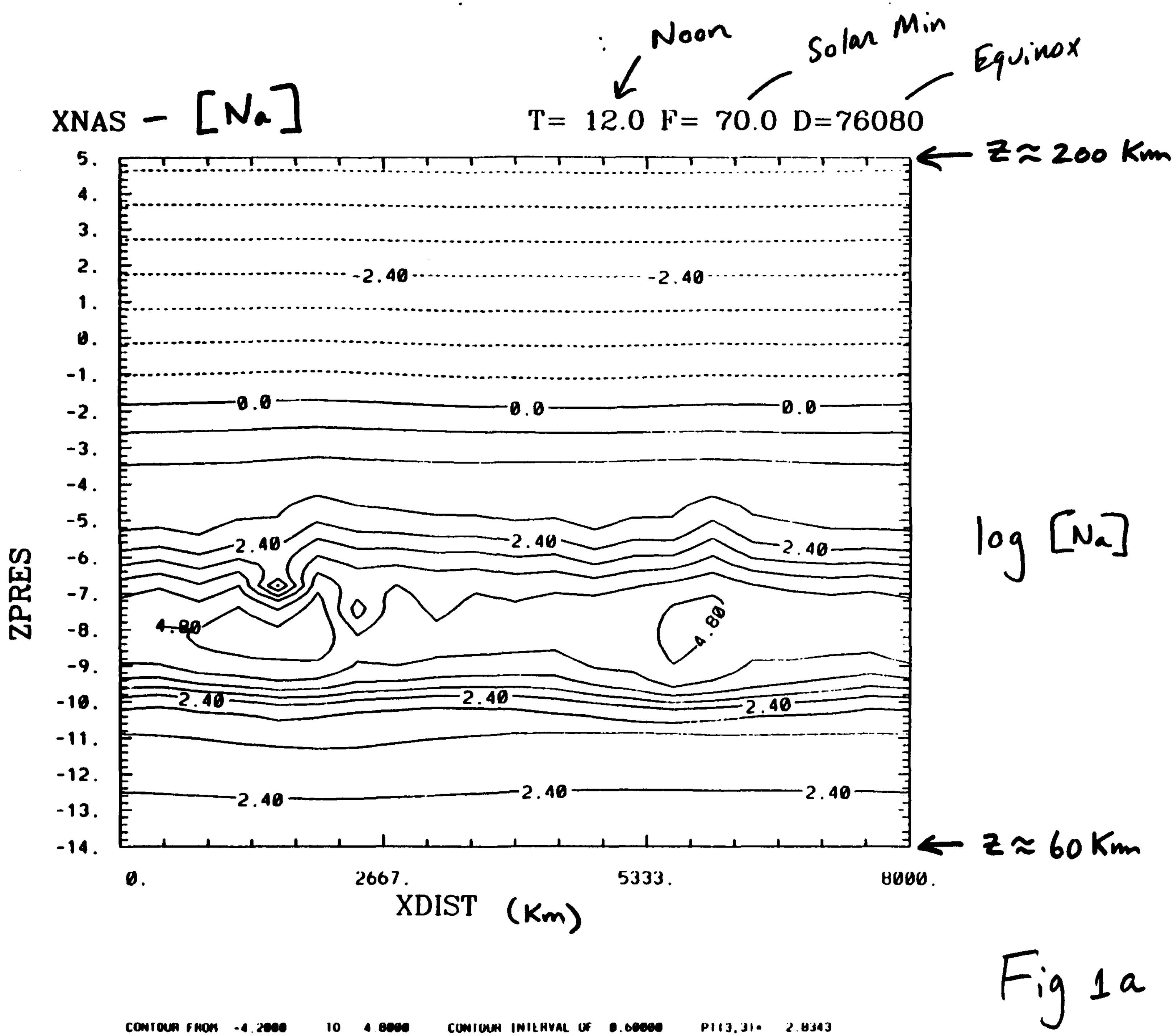
Noon
Solar Min
Equinox
XNAS - [Na]
T= 12.0 F= 70.0 D=76080
Z ≈ 200 Km
Z ≈ 60 Km
log [Na]
ZPRES
XDIST (Km)
0.
2667.
5333.
8000.
-2.40
0.0
2.40
4.80
CONTOUR FROM -4.2000 TO 4.8000 CONTOUR INTERVAL OF 0.60000 PT(3,3)= 2.8343

Fig 1a

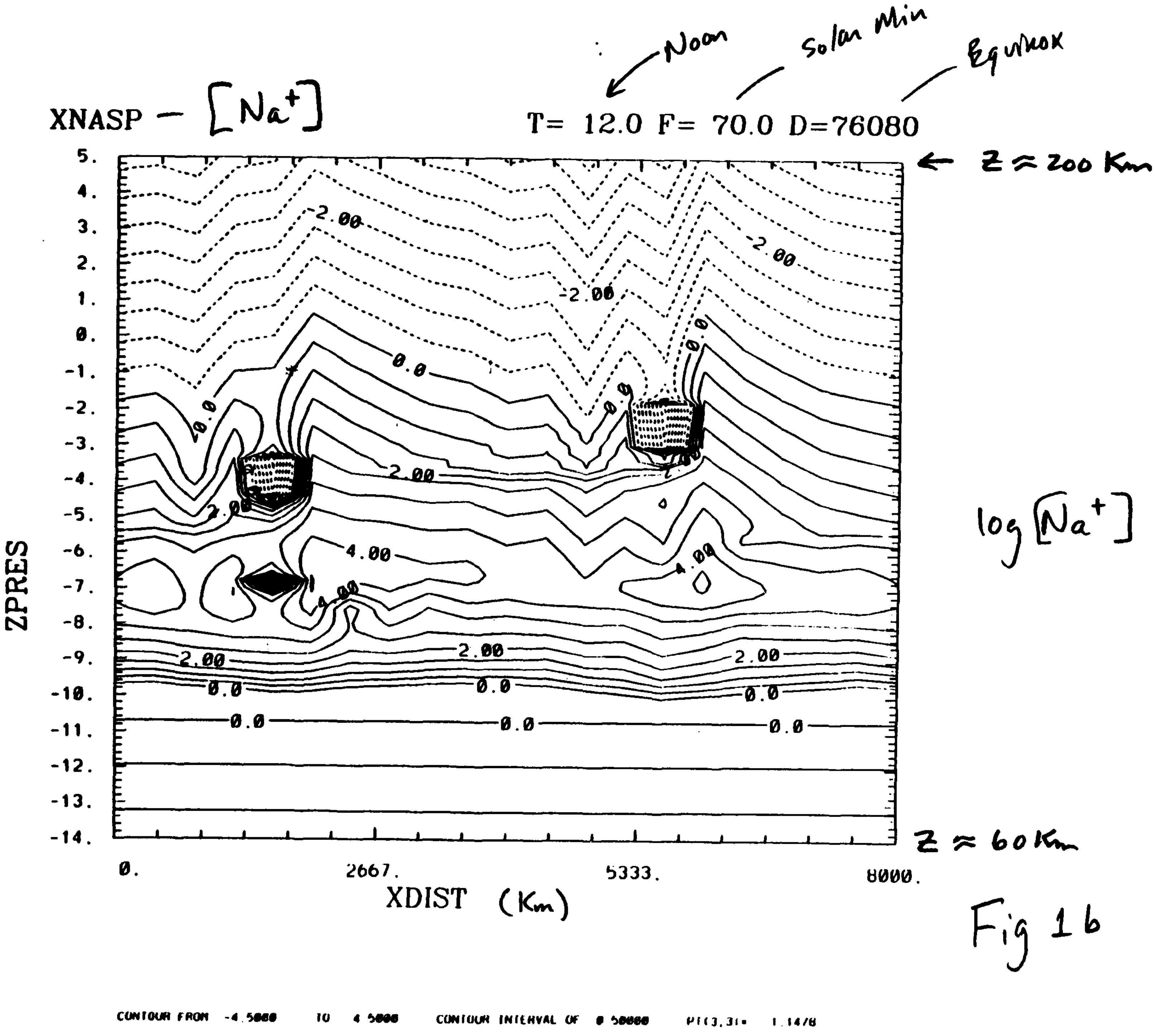
Noon
Solar Min
Equinox
XNASP — [Na+]
T= 12.0 F= 70.0 D=76080
Z ≈ 200 Km
Z ≈ 60 Km
log [Na+]
ZPRES
XDIST (Km)
0.
2667.
5333.
8000.
-2.00
0.0
2.00
4.00
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Fig 1b

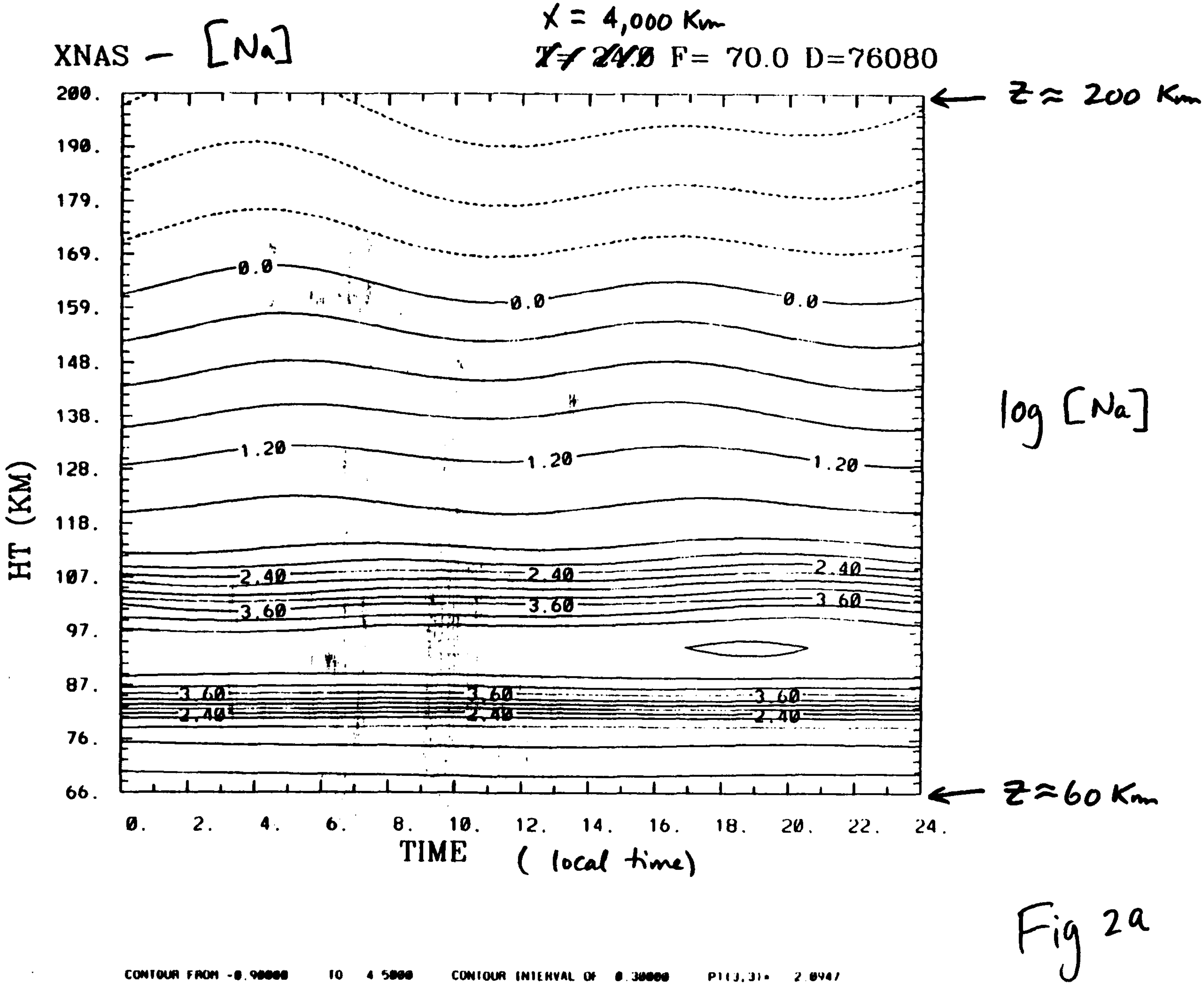
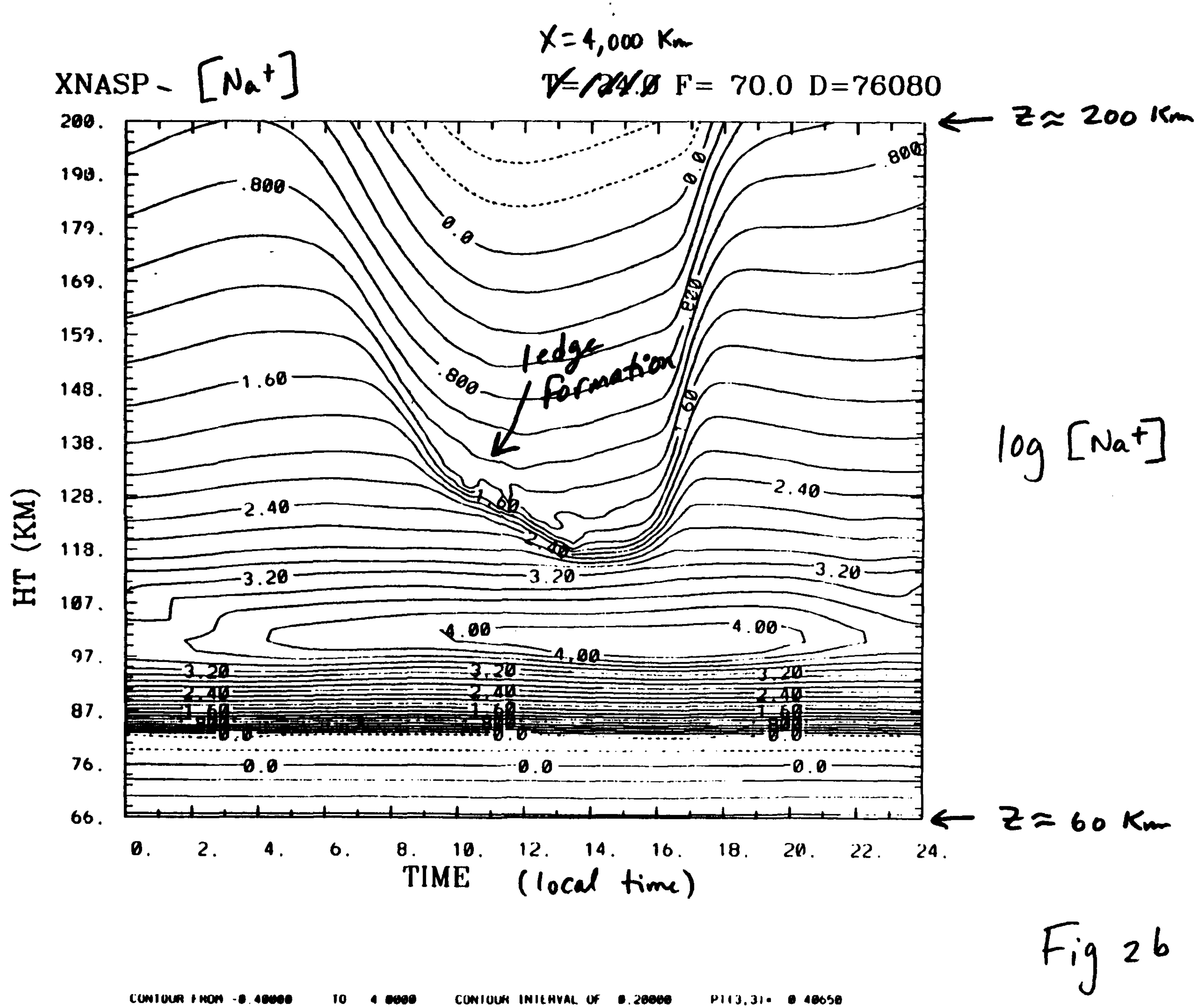

XNAS — [Na]
X = 4,000 Km
F= 70.0 D=76080
HT (KM)
200.
190.
179.
169.
159.
148.
138.
128.
118.
107.
97.
87.
76.
66.
0.0
1.20
2.40
3.60
0. 2. 4. 6. 8. 10. 12. 14. 16. 18. 20. 22. 24.
TIME (local time)
z ≈ 200 Km
z ≈ 60 Km
log [Na]
CONTOUR FROM -0.90000 TO 4.5000 CONTOUR INTERVAL OF 0.30000 PT(3,3)= 2.0947

Fig 2a



X=4,000 Km
XNASP - [Na+]
T=~~24.0~~ F= 70.0 D=76080
← z ≈ 200 Km
← z ≈ 60 Km
HT (KM)
200.
190.
179.
169.
159.
148.
138.
128.
118.
107.
97.
87.
76.
66.
0.
2.
4.
6.
8.
10.
12.
14.
16.
18.
20.
22.
24.
TIME (local time)
.800
0.0
1.60
2.40
3.20
4.00
ledge formation
log [Na+]
CONTOUR FROM -0.40000 TO 4.0000 CONTOUR INTERVAL OF 0.20000 PT(3,3)= 0.40650

Fig 2b

$\log_{10}[Fe^+]$ m^{-3}

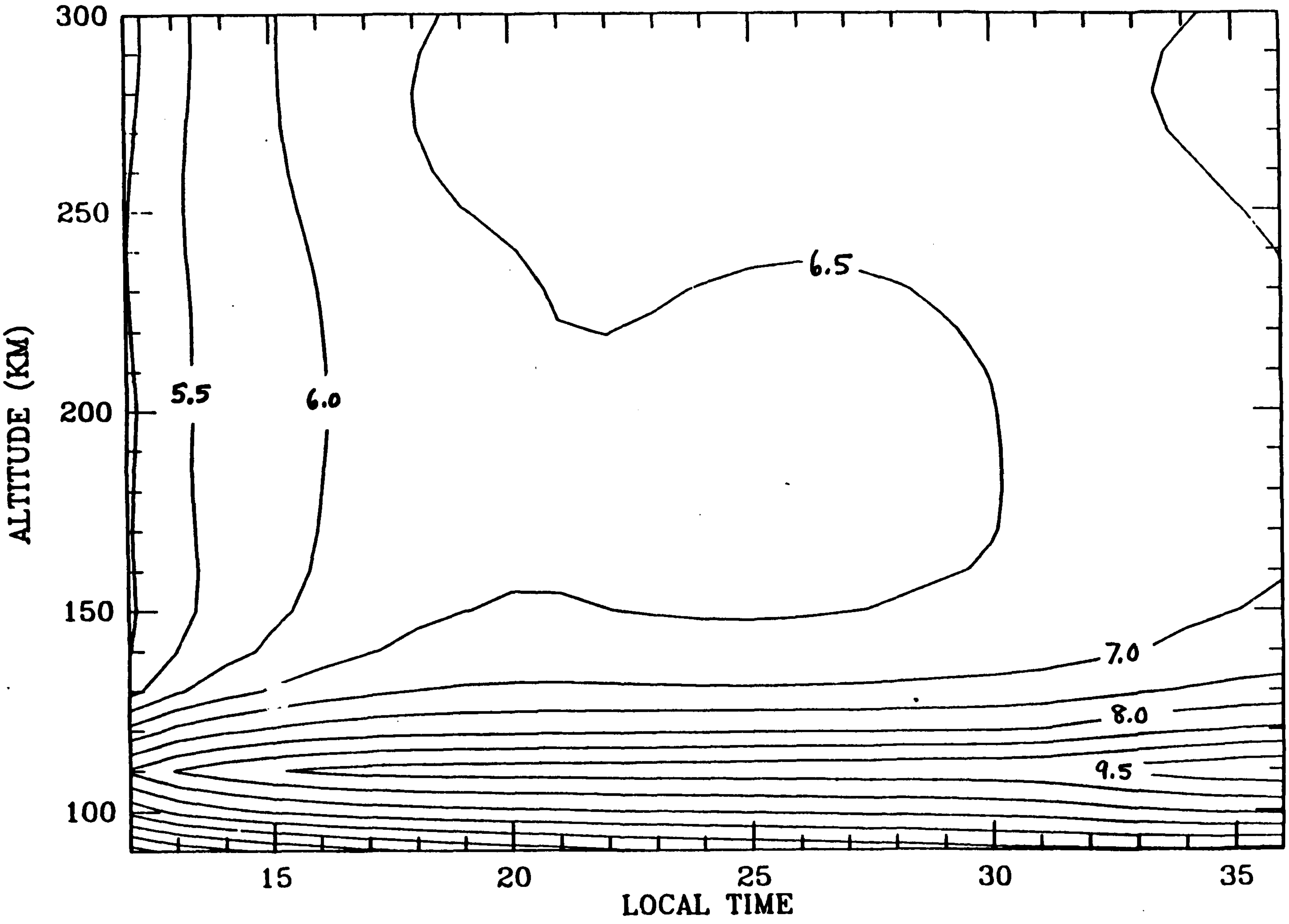


Fig. 3

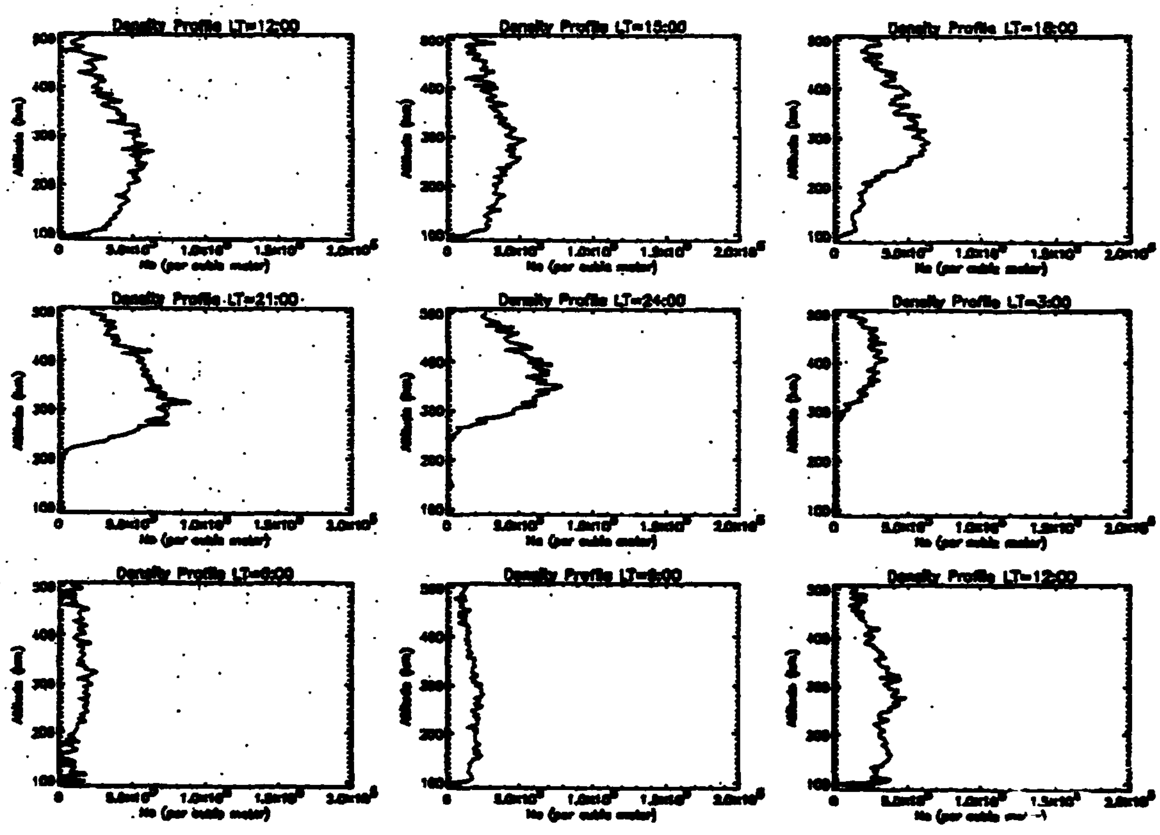


Figure 4. Electron Density vs Altitude for Select Times.

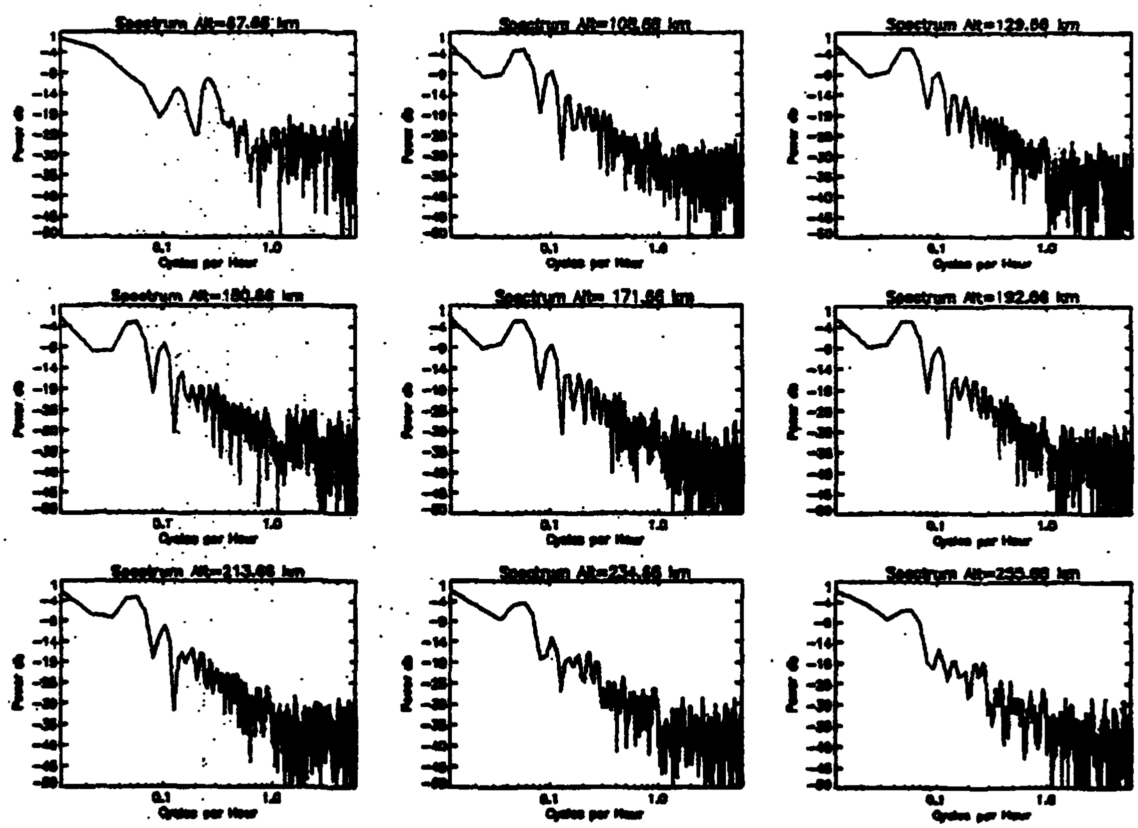


Figure 5. Spectrums of Density Variations for Select Altitudes.

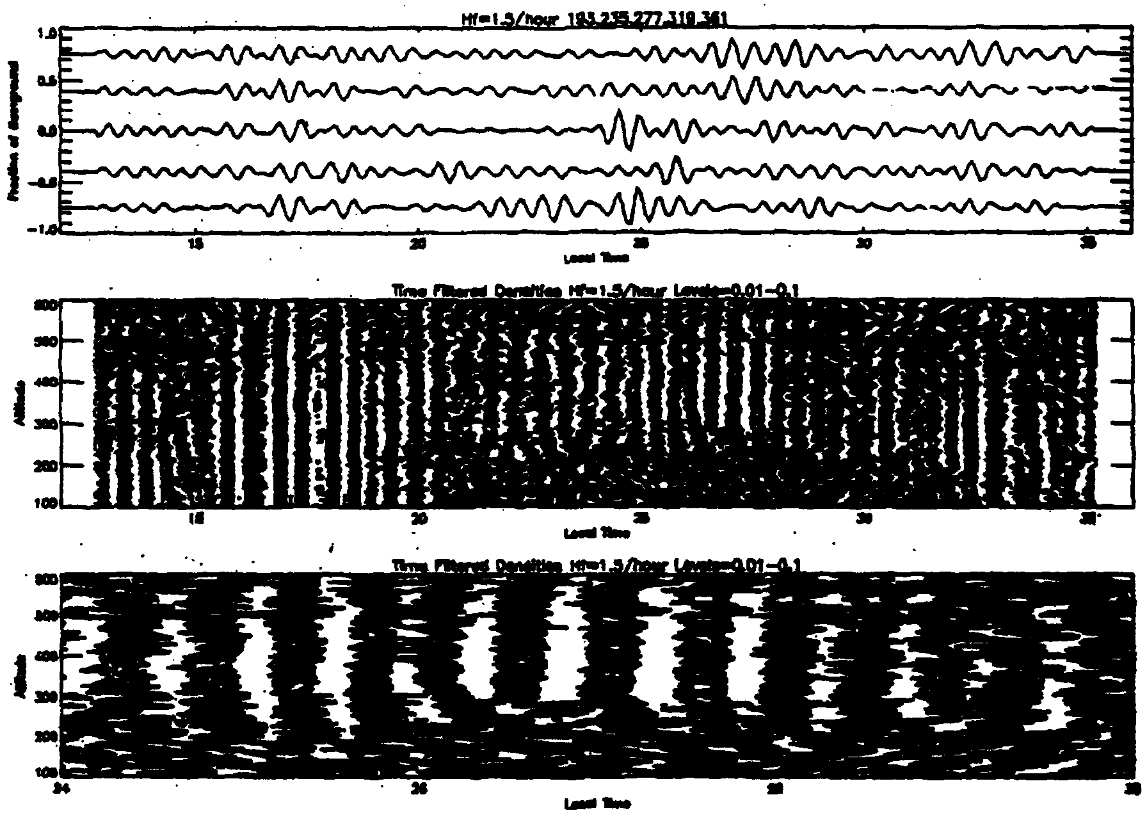


Figure 6. Time Filtered Density Variations.